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Forests and global warming mitigation in Brazil: opportunities in the Brazilian forest sector for responses to global warming under the "clean development mechanism"

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Abstract

The Kyoto Protocol created global warming response opportunities through the clean development mechanism that allow countries like Brazil to receive investments from companies and governments wishing to offset their emissions of greenhouse gases. Brazil has a special place in strategies for combating global warming because its vast areas of tropical forest represent a potentially large source of emissions if deforested. A number of issues need to be settled to properly assign credit for carbon in the types of options presented by the Brazilian forest sector. These include definition of the units of carbon (permanent sequestration versus carbon-ton-years, the latter being most appropriate for forest options), the means of crediting forest reserve establishment, adoption of discounting or other time-preference weighting for carbon, definition of the accounting method (avoided emissions versus stock maintenance), and mechanisms to allow program contributions to be counted, rather than restricting consideration to free-standing projects. Silvicultural plantations offer opportunities for carbon benefits, but these depend heavily on the end use of the products. Plantations for charcoal have the greatest carbon benefits, but have high social impacts in the Brazilian context. Plantations also inherently compete with deforestation reduction options for funds. Forest management has been proposed as a global warming response option, but the assignment of any value to time makes this unattractive in terms of carbon benefits. However, reduced-impact logging can substantially reduce emissions over those from traditional logging practices. Slowing deforestation is the major opportunity offered by Brazil. Slowing deforestation will require understanding its causes and creating functional models capable of generating land-use change scenarios with and without different policy changes and other activities. Brazil already has a number of programs designed to slow deforestation, but the continued rapid loss of forest highlights the vast gulf that exists between the magnitude of the problem and the efforts to address it. The ups and downs of Brazil's deforestation rate have so far had little to do with deliberate programs to control or influence the process. Achieving this control will require a major effort in which contributions from the private sector will be needed. Mechanisms are needed to make contributions to such programs eligible for carbon credit.

Keywords: Brazil; Amazon; Global warming; Carbon sequestration; Tropical forest; Greenhouse effect; Kyoto Protocol

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1. The Kyoto protocol and global warming response opportunities

The clean development mechanism (CDM) was included in the December 1997 Kyoto Protocol as a proposal from the government of Brazil to create a means whereby countries not accepting binding emissions limits could cooperate on a project-specific basis with countries that had agreed to limitations (Annex I countries) in reducing emissions. The CDM, defined in Article 12 of the protocol, calls for real, additional, and cost-effective reduction of net carbon emissions. The forest sector in Brazil offers considerable scope for activities within the CDM, including opportunities for private sector investors. However, a number of institutional and policy mechanisms must be established by the government and international agencies to ensure that these activities meet the objectives of the CDM. Additionally, in certain countries (such as The Netherlands) national programs allow companies to avoid paying emissions taxes if the companies undertake acceptable carbon offset measures anywhere in the world.

The discussion that follows explains the place of Brazil in combating global warming, outlining opportunities presented by the country's forest sector and the obstacles that must be overcome to turn these into global warming response options. Unsettled issues in assigning credit for carbon include deciding whether carbon is counted on the basis of permanent sequestration versus carbon ton-years, methods for crediting forest reserve establishment and for crediting avoidance of "natural" disasters, application of discounting or other time-preference weighting to carbon, and deciding whether credit will be based on avoided emissions or on stock maintenance. In addition, credit for efforts to combat deforestation will require acceptance of contributions to larger programs, rather than restricting recognition to free-standing projects.

The opportunities and challenges of each class of activity in Brazil's forest sector are analysed. Silvicultural plantations are examined in terms of their carbon benefits, social impacts, and competition with deforestation reduction. Forest management is examined in terms of the means of crediting carbon benefits and the potential for avoiding emissions through reduced-impact logging. Slowing deforestation requires understanding the causes of deforestation, the magnitude of greenhouse gas emissions from deforestation, and the existing programs to slow forest loss. Finally, the potential role of the private sector is considered in efforts to combat global warming in these areas.

2. The place of Brazil in combating global warming

Brazil is not just any country in matters related to tropical deforestation. It is not just "one of the most important" countries: it is <u>the</u> most important country both from the standpoint of remaining tropical forest and from the standpoint of current annual deforestation rate (and therefore in terms of potential emissions both on a total and on an instantaneous basis). Brazil's "legal Amazon" region, composed of all or part of nine states, covers 5 million km^2, of which 4 million km^2 was originally forested (Fig. 1). Approximately 3.5 million km^2 (87%) of this originally forested area was still standing as of 1997. Later in this paper the ups and downs of Brazil's Amazonian deforestation rates will be discussed in some detail.

One must ask why developed country governments and private companies are interested in Brazil as a site for forest sector responses to global warming. If they are looking for a safe country where they can plant trees, they should go to Costa Rica instead of Brazil. The attraction of Brazil is obvious: the country's areas of land and forest, and the scale of the national economy, are sufficiently large that changes in Brazil would affect climatically significant quantities of carbon. The rationale for locating a small tree-planting project in Brazil rather than Costa Rica, for example, would be the potential for a demonstration effect in Brazil that could influence the fate of much larger amounts of carbon than those directly involved in the proposed plantation. One must face this aspect of the decision-

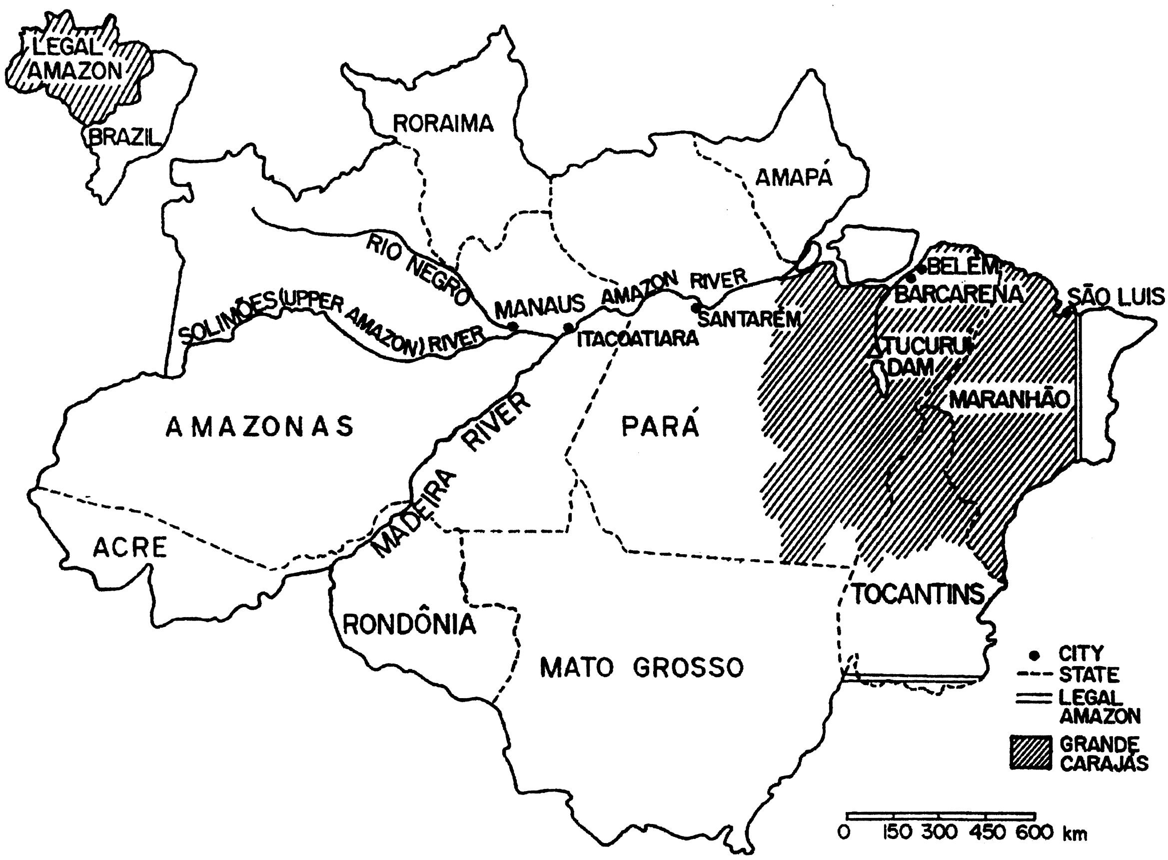

Fig. 1. Brazil and the legal Amazon region.

making process squarely and quantitatively, rather than leaving it as an unstated backdrop to project-level calculations of carbon and money balances for particular response option proposals.

In Brazil, the greatest potential for global warming benefits lies in slowing deforestation—not in planting trees, reducing the country's fossil fuel consumption, or other activities. Brazil's Amazonian deforestation emits approximately $250–350\times10^6$ tC annually, depending on the method of calculation (to be discussed in greater detail later in this paper), as compared to approximately 60×10^6 tC from fossil fuels. It is a much more difficult and unstudied task to slow deforestation and assign proper credit to the different actions that are either taken with this objective or that occur for unrelated reasons. The probability of spending money and having nothing to show for it is much higher, even if the size of the prize if success is achieved is also much higher.

In both gambling and business investment, a Bayesian view of evaluating different outcomes is essential. The expected monetary value (EMV) if the outcome of a bet or an investment is the net value of the outcome (the "prize", expressed as benefits minus costs) multiplied by the probability of its occurrence. If several possible outcomes exist, EMVs are calculated and summed to obtain the value at the point where the decision is to be made (see Ref. [1]).

In the present case, slowing deforestation has a potential return many times larger than that from more common global warming response options. However, the risk of failure is high, as is the uncertainty as to what the true probability of success is.

3. Unsettled issues in assigning credit for carbon

3.1. Permanent sequestration versus carbon ton-years

Carbon accounting needs to be done on a carbon ton-year basis rather than on the basis of "permanent" sequestration if comparisons are to be made between forest reserve creation and policies to slow deforestation. Ton-year accounting is also needed for comparing avoided fossil fuel emissions with silvicultural plantations and other mitigation options in the forest sector. Under a ton-year system, credit would be given for the number of tons of carbon held out of the atmosphere each year. Discounting, zero or otherwise, would apply to the carbon value calculated for each year over the time horizon when the expectations for different proposed mitigation projects are compared. Keeping a ton of carbon out of the atmosphere during any given year has the same value whether carbon atoms are cycled through successive batches of paper, each lasting only a few weeks or months, or whether the carbon atoms are in a mahogany desk that lasts a century. Under a ton-year accounting system, delaying deforestation merits credit irrespective of the long-term fate of the forest, although the cumulative credit that can be earned from a given patch of forest is obviously greater the longer the forest remains standing.

The manner in which carbon credits are calculated can determine whether policy change mitigation options are subject to "leakage", or negation of the carbon benefits by events outside a given project area that are set in motion by the mitigation activity. Because the policy change approach focuses on national-level totals (whether these totals be of flows or of stocks), no "leakage" can occur through changes in the spatial distribution of deforestation activity within the country, as by movement of potential deforestation from a reserve to another forested area. Displacement of deforestation in time, however, can result in leakage if the accounting procedure requires "permanent" sequestration in either specific areas of forest or in the forest sector of a whole country [2].

3.2. Crediting forest reserve establishment

The current criterion of "incremental costs" implies that establishing a park in an area of forest that would not be cleared receives no credit, whereas one in an area experiencing rapid clearing is heavily rewarded. The park in the area with little clearing is likely to be cheaper to establish. How carbon credits are allotted can therefore influence where parks are created. Depending on how benefits are counted, areas with the greatest benefit for a given investment in carbon offsets will not be the same areas that would be chosen for maintaining biodiversity [3]. In Brazil, the least well-protected and most threatened types of forest are along the southern boundary of Amazonia where reserve establishment is relatively very expensive per unit of area [4]. This effect is compounded by these forests having lower biomass than those in more remote areas in central Amazonia [5].

The crediting of forest reserve establishment has recently been brought to world attention by the government of Costa Rica's 24 April 1998 announcement that certified tradable offsets (each corresponding to 1 t of carbon) are available for sale for 5000 km^2 of forest in that country [6]. Costa Rica hopes to obtain approximately US\$40 ha^{-1} $year^{-1}$ from the program over a 15-year period. The plan has been certified by Societé Generale de Surveillance Holding, a Swiss company, to "remove" at least 1 million t of carbon from the atmosphere annually.

3.3. Crediting avoidance of "natural" disasters

The fires that raged out of control in Brazil's far northern state of Roraima from December 1997 to March 1988 made clear that avoidance of "natural" disasters represents a major factor in the carbon balance of tropical forests, and one that should be addressed in global warming mitigation strategies. Although widely disparate statements have been made on the extent of burning in standing upland forest, only one estimate exists based on a methodology other than guesswork: overflights of flame lines with locations determined using a global positioning system (GPS), plotting locations on a map, scanning the map and the measuring the areas using graphical software. An estimated 7160 km^2 of standing upland (terra firme) forest burned [7]. Although the percentage of trees killed within this area is relatively small, the vast area involved ensures that carbon emissions, including committed emissions, are substantial. These emissions are currently being estimated.

The Roraima fires occurred during an El Niño event, but they would not have occurred without human intervention. The fires most damaging to forest began in settlement areas which were installed in the forest by the government in the early 1980 s, thus providing fire initiation foci. It is significant that these settlement areas were deliberately implanted by the government, as opposed to being locations where migrants spontaneously invaded areas of forest with the government's role being restricted to legalizing a fait accompli. The likelihood of fires escaping into surrounding forest has never been considered in weighing the costs and benefits of decisions on settlements and other development projects. Lessons from the events in Roraima need to be learned such that future decisions take this into account.

Logging had not affected most of the forests burned in Roraima in 1998, but this activity is widespread in other parts of the legal Amazon where fire risk is substantial. Logging increases the flammability of the forest by leaving dead wood in the forest in the form of branches and other unused portions of harvested trees and by killing many trees in addition to those harvested. This has been documented in logging areas in Eastern Amazonia [9, 10]. Logging has been rapidly expanding in many parts of the region, and can be expected to increase even more rapidly in the future as Asian forests are no longer able to supply the volume of wood demanded by global timber markets.

Settlements are a steadily increasing feature of the landscape in Amazonia, as is the building and improvement of roads. The political process through which settlements and roads are built leads to a positive feedback relationship between these developments, tending to accelerating deforestation [11]. Brazil's national government has announced ambitious targets for agrarian reform in response to escalating social tensions between landless farmers and large landholders. Over the 1987–1996 period, 145,000 families were settled throughout the country, but 4.8 million families still remained landless [12]. The temptation is ever-present to distribute land in forested areas in Amazonia to this landless population, as also occurred in past agrarian reform programs, rather than facing the politically more difficult alternative of redistributing degraded pastureland on unproductive large landholdings. Already deforested areas invariably have owners who represent a political force against expropriating the areas for agrarian reform. An area the size of France has been deforested in the legal Amazon, much of which is now degraded cattle pasture and secondary forest. The environmental cost of fire escaping into standing forest provides an important argument in favor of the government establishing a policy that all new settlements will be in this already deforested area, well away from areas of standing forest.

3.4. Discounting or other time preference weighting

It could be argued that postponing deforestation is a valid mitigation measure even if the forests in question are later cut, including cutting up to the theoretical maximum of clearing all forests in a country. The credit for such a delay depends on two key parameters: time horizon and discount rate (or other alternative time-preference scheme). Decisions on these parameters, including using an infinite time horizon or a zero discount rate, reflect moral values and should be approached through democratic means. From a carbon perspective, under some conditions postponing a given number of hectares of clearing for a year is equivalent to avoided emissions by reduced combustion of fossil fuels. In the fossil fuel case, avoided emissions are counted as a permanent gain, even though the same barrels of oil not burned in one year will be burned just one year later. The fossil fuel displacement is assumed to cascade forward, either (1) indefinitely (i.e. assuming that fossil fuel stocks are infinite for practical purposes), (2) until after the end of the time horizon, or (3) until fossil fuel burning ceases at some fixed point in time due either to development of technological alternatives or to enlightenment and social changes. In the case of deforestation, these assumptions can break down if the area of remaining forest is small enough that it could be exhausted within the time horizon under consideration. If a country runs out of forest (or of accessible or unprotected forest) within the time horizon, then no carbon advantage would accrue from postponing deforestation if the discount rate is zero.

The discount rate for carbon need not be zero, although zero discount rate is the current practice of the global environment facility (GEF) in evaluating proposed mitigation projects. A discount rate greater than zero is justified by the fact that a given increase in temperature through global warming does not produce a one-time impact, but rather raises the frequency of droughts, floods and other undesirable events from that time forward. If global warming is delayed from time 1 to time 2, the impacts that would have been suffered between time 1 and time 2 represent permanent savings, thereby giving time a value independent of any additional value that might be assigned to it on the basis of selfish motives on the part of the current generation. A value for time is translated into economic decision-making by use of a discount rate (or equivalent). Discounting can radically alter choices of energy sources and mitigation options [3, 13].

3.5. *Avoided emissions versus stock maintenance*

Maintaining carbon stocks where they are in the standing biomass of natural forests represents an important global warming response option for Brazil. This must not be allowed to fall victim to the tendency to restrict discussion of options to increasing flows of carbon from the atmosphere into various other sinks. It is important to remember that emissions reduction is a means to an end: the objective of the framework convention on climate change (FCCC) is defined in the convention in terms of avoiding "dangerous levels" of greenhouse gases (GHGs) in the atmosphere (i.e. in terms of stocks, not flows).

Carbon stock maintenance is not currently recognized by FCCC protocols, but strong arguments exist for incorporating this form of environmental service into global warming mitigation policies [2, 14]. In a stock maintenance calculation, the size of a carbon pool (for example, carbon in the forests of Brazil's legal Amazon region) is rewarded with a yearly payment, similar to interest on a savings account. Considering 1990 values (the base year for inventories under the FCCC), Brazil would stand to gain approximately ten times more from a carbon stock maintenance accounting approach than from an avoided emissions approach, assuming an annual discount rate of 5% [15].

If carbon stock maintenance were recognized as a form of mitigation measure, as distinguished from avoided deforestation, then monitoring needs would be much simpler from the point of view of countries contributing funds as carbon credits: only accompaniment of forest stock remaining each year would be necessary. Brazil, as a recipient of credits, would still find that its national interests are best served by having more detailed information, such as at the property level, in order to understand the deforestation process and to control or influence it effectively to maximize benefits of retaining forest, including its carbon credit benefits. Recognition of the value of forest carbon stock would greatly increase the value credited to areas with large stocks relative to annual losses to deforestation, as is the case in Brazilian Amazonia. This would increase the need for effective monitoring of forest areas, biomass stocks, and processes of forest loss and degradation.

Any deforestation avoidance project in Brazil has the potential of affecting the fate of one of the Earth's major carbon stocks. This contrasts with the situation in many smaller tropical countries. For example, the ultimate impact of a project in Costa Rica is the possibility of saving the tiny remnants of forest left within that small country, plus a tenuous indirect connection to remaining tropical forests of the world through any lessons learned or demonstration effects that may be gained from the projects. In Brazil's case, where large expanses of forest remain standing, stock maintenance represents a much greater carbon service than does avoiding deforestation, even though this is also a large service. Gaining recognition of stock maintenance as a service to be compensated is where Brazil should apply its diplomatic influence.

One difficulty in gaining recognition of forest carbon stock maintenance as a benefit is the fear that the same arguments might be used with regard to fossil fuel carbon stocks, thereby making any form of credit inviable in practice. The world's "available" fossil fuel carbon stocks total approximately 5000×10^9 tC versus a total tropical forest carbon stock requiring maintenance of 216.8×10^9 tC (see Appendix). Conversion of Brazil's Amazon forest to a replacement landscape reflecting current trends [16] would release an estimated 76.8×10^9 tC, or 35% of the total potential net release from the world's tropical forests.

One relevant difference between carbon stocks in forests versus fossil fuels is that population growth and technology for changing land uses have advanced to the point where all biosphere carbon stocks are effectively at risk of clearing within a century, whereas only the tip of the vast iceberg of deposits of fossil fuels, especially coal, could realistically be burned over the same time horizon. In addition, active defense of forests is needed to keep them standing, whereas fossil fuel use rates are more easily influenced through economic policy instruments such as taxes and tariffs. The value of forests for climatic functions other than carbon stocks and for maintaining biodiversity and indigenous cultures provide additional reasons to treat them differently from fossil fuel reserves.

3.6. Free-standing projects versus program contributions

Response options under the CDM are normally viewed as free-standing self-sufficient achievements that keep a quantifiable amount of GHGs out of the atmosphere. For example, one may plant trees within the bounds set by financial and other resources: the scale of such actions can, theoretically, be as small as one might like, down to the ultimate lower limit of planting (and caring for) only one tree. Carbon benefits from this can be calculated, and the continued presence of the tree(s) can be monitored. However, fighting global warming in this way may not be the best use of the opportunity presented by funds made available as a result of the Kyoto Protocol.

We must consider valid response options as including all of the deforestation-avoidance process (as opposed to only the end-point of achieving specific levels of reduction), and must accept criteria to judge success other than the number of tons that are guaranteed to be held out of the atmosphere, as in fossil fuel substitution or energy efficiency projects. If we are designing a plan to find a cure for a major disease, such as cancer or AIDS, we do not consider any advances short of finding "the" cure as failures. Rather, we produce a long series of incremental advances moving toward this ultimate objective. Money has not been wasted in achieving these steps, even though no survivors can be pointed to. Even in the case where a "cure" is found and survivors can be counted, credit cannot easily be apportioned among the different steps in the chain that led to the "cure".

4. Silvicultural plantations

4.1. Carbon benefits

So far, Brazilian proposals for forest-sector response options to combat global warming have centered on plantations. Best known is the 20 million ha FLORAM proposal prepared by a group led by the University of São Paulo's

Institute of Advanced Studies [17]. Although the carbon calculations in the proposal exaggerate benefits by using the biomass of the plantations at the maximum point in the cycle (the point of harvest), and by considering only the process of carbon fixation rather than the effect on carbon stocks [18], plantation alternatives do indeed represent a means of removing substantial amounts of carbon from the atmosphere. This is particularly true when they can be used for fossil carbon substitution, as in the case of plantations for charcoal production.

The carbon stocks in biomass and wood products for a given area of plantation are relatively easy to calculate, despite uncertainty. The carbon consequences of a program of plantations as a response option are much more difficult to assess. A program-level analysis must not only consider the plantation itself, but also the surrounding landscape to which people may have relocated when the plantation was installed. A credible scenario with and without the plantation program has to be constructed to allow a comparison. Project-level calculations have been presented elsewhere [3], but program-level calculations still do not exist.

Project-level calculations provide an incomplete picture because of "leakage" of the carbon benefits. Plantation projects cause effects in other locations through markets for wood products and migration of human population [19]. The products made from the wood substitute for products that, in the absence of the project, would have been derived from wood coming from other sources (natural forests or plantations elsewhere). For wood products, the net gain is only the increase in the total stock of wood products that would result from greater supply (and lower price) of these commodities due to existence of the project (an amount that is inevitably always much less than the total production of the project).

The carbon benefits of plantations depend heavily on the end use of wood produced. Substitution of fossil fuel has much greater potential benefit than stocking carbon in standing biomass in plantations or in wood products made from harvested trees. This is because each ton of fossil fuel carbon replaced is considered to be a permanent gain, whereas the flux of carbon to biomass or wood product pools reverts to the atmosphere later, such that the net flux is zero after the size of these stocks reaches an equilibrium. This is what gives plantations for charcoal a great advantage in terms of carbon benefits over other types of plantations.

4.2. Social impacts

The major concerns regarding large-scale expansion of plantations in Brazil as a global warming response option are social rather than environmental or technical. The FLORAM project is envisaged as being composed of plantations divided into relatively small blocks so that the local population would have sufficient space for food production in the areas between the silvicultural blocks: "Doubling planted forests in spaces covering 100,000 or 200,000 ha, in the context of rural Brazil, would be a crime committed against the future of a country that needs to develop its agriculture and discover the correct guidelines for a process of agrarian reform. For this reason, we envisage that the technical reserves of the commercial plantations should not occupy spaces greater than 15,000 or 20,000 ha, separated from each other by 25 to 40 km at the minimum" (Ref. [20], page 110). It is obvious that this vision differs from the present pattern, where a number of companies have over 200,000 ha of continuous plantations. The present spatial pattern is not a random event: it is the result of economies of scale and minimization of costs for transport and management. If the spatial pattern adopted is the one recommended by the FLORAM project, this would imply an additional financial cost, which would be the price of avoiding the social impacts provoked by vast expanses of continuous eucalyptus that the expansion of silviculture produces in a laissez faire scenario [21].

The attractiveness of charcoal manufacture from the standpoint of carbon benefits contrasts sharply with the social effects of charcoal as compared to other plantation end-uses, such as pulpwood. Charcoal manufacture in Brazil is closely linked to a system of debt slavery that has been the center of domestic and international outrage. In 1994 public attention was drawn to the existence of slavery in Brazil when denunciations were brought before the International Labor Organization in Geneva [22–24]. Charcoal is frequently manufactured by families, including children, who work for an intermediary who supplies charcoal to legitimate businesses such as pig-iron mills. The charcoal workers are obliged to buy all supplies from their patron and, given the high prices charged for the supplies and the small amounts credited per unit volume of charcoal produced, the debts grow inexorably and become impossible to liquidate. In practice, workers never receive any payment in cash—only credit towards paying off past debts. Gunmen assure that the workers cannot run away, the only exit from the system being death.

The debt slavery system violates Brazil's labor legislation, but is tolerated in practice. In 1997 Brazil began a pilot project to combat the use of child labor by charcoal-making operations in the state of Mato Grosso do Sul, but no such program has begun in the Carajas region of Para and Maranhao where silvicultural plantations for charcoal manufacture are likely to be located. The Carajas region is the site of the world's largest high-grade iron ore deposit, providing a major potential demand for charcoal for pig-iron manufacture [25].

Theoretically, the offer of international financing for plantations to be used for charcoal production could be used as an inducement for the Brazilian government to end the debt slavery system. Such a scenario would require more than paper threats that no funding would be forthcoming unless independent monitoring established that appropriate measures had been taken to ensure that Brazil's labor legislation is respected in all activities associated with the plantations and their products. Penalties for noncompliance would have to go beyond suspension of subsequent payments, as demonstrated by the case of charcoal manufacture in the Carajas area using wood from native forests: the World Bank's loan to the Carajas Iron Project became an international scandal when Brazil violated environmental clauses in the loan agreement with complete impunity after disbursements had been completed [25].

4.3. Competition with deforestation reduction

The most basic problem with promoting silvicultural plantations as a global warming response option is the effect that expenditures on these programs would have on the priority given to avoiding deforestation. Since funds available for combating global warming are inevitably limited, these two approaches compete with each other.

Brazilian emissions from deforestation in Amazonia are very large, as will be discussed later in this paper, and any reduction in the rate of deforestation would therefore bring large carbon benefits. Reducing deforestation rates is a much more attractive area than promoting silvicultural plantations as a strategy for combating global warming [3].

5. Forest management

5.1. Crediting forest management

A response option such as sustainable management of native forest for timber may seem reasonable, theoretically stocking carbon in long-lasting wood products made from tropical timber. However, even under the unrealistically optimistic assumption adopted here of perfect compliance with management plans, sustainable management does not constitute a global warming "response option" when compared to native forest.

In addition, proposals for sustainable management as a response option invariably presume that the timber management system is not only sustainable in silvicultural terms but is also sustainable in practice—rather than serving as the first step in the process of deforestation. Were analysis of timber management to include realistic probabilities of the system being perverted to deforestation (probabilities that most likely have values closer to one than to zero), the result would be very large net releases of carbon. The problem lies in fundamental contradictions between maximizing financial return to the primary actors in implanting forestry management for timber, and the criteria applied by those interested in promoting sustainable systems for other reasons, including carbon benefits [26].

Carbon benefits or losses attributable to sustainable timber management will obviously be very different depending on whether one assumes that the alternative is uncut forest or whether it is unsustainable logging or deforestation. As compared to forest, sustainable timber management represents a net carbon loss. Estimates of carbon costs and benefits of timber management have been presented elsewhere [3].

5.2. Reduced-impact logging

Reduction of logging damage in existing forest management schemes can have significant carbon benefits at moderate cost [27–29]. A major forest management initiative has been underway since 1994 near Itacoatiara, Amazonas, by Mil Madeireira Itacoatiara, Ltda., owned by the Swiss company Precious Woods. This company manages 50,000 ha of an 80,000 ha property, selectively logging 2000 ha annually in what is planned to be a 25-year cycle. Investment in the venture has already exceeded US$27 million, making it unlikely that it would take place but for idealistic motivation of the investors (mainly Swiss doctors and lawyers). However, the experience gained can be expected to make future ventures much more cost effective. The venture is not currently contemplating carbon benefits, although this would be a logical direction for the company to take.

6. Slowing deforestation

6.1. Understanding the causes of deforestation

A prerequisite to any program to slow deforestation is that the causes driving it must be understood. Our knowledge of deforestation processes is still imperfect; contributions to better understanding the process therefore represent a key area in which effort is needed in order to avoid forest loss and consequent greenhouse gas emissions. A tremendous spectrum of opinion exists as to who is to blame for deforestation in Brazilian Amazonia; however, these opinions vary equally widely in the factual basis supporting them. Examination of several lines of available evidence indicates that ranchers (both medium and large) are the main agents of clearing.

The relative weight of small farmers versus large landholders in Brazilian Amazonia is continually changing as a result of changing economic and demographic pressures. Behavior of large landholders is most sensitive to economic changes such as interest rates offered by money markets and other financial investments, government subsidies for agricultural credit, rate of general inflation, and changes in the price of land. Tax incentives were a strong motive in the 1970 s and 1980 s. In June 1991, a decree suspended the granting of new incentives. However, the old (i.e. already approved) incentives continue to the present day, contrary to the popular impression that was fostered by numerous statements by government officials to the effect that incentives had been ended. Many other forms of incentives, such as large amounts of government-subsidized credit at rates far below those of Brazilian inflation, became much scarcer after 1984.

Hyperinflation was the dominant feature of the Brazilian economy for decades preceding the initiation of Brazil's Plano Real economic reform program in July 1994. Land played a role as a store of value, and its value was bid up to levels much higher than what could be justified as an input to agricultural and ranching production. Deforestation played a critical role as a means of holding claim to land (see [11]). Deforesting for cattle pasture was the cheapest and most effective means of maintaining possession of investments in land regardless of the reasons behind the profitability of the ventures. The extent to which the motive for defending these claims (through expansion of cattle pasture) was speculative profits from increasing land value has been a matter of debate. Hecht and coworkers [30] present calculations of the overall profitability of ranching in which contribution from speculation is critical, while Mattos and Uhl [31] find that actual production of beef has become increasingly more profitable, and that supplementary income from selling timber (allowing investment in recuperation of degraded pastures on the properties) is critical. Obviously, selling off the timber can only be depended upon for a few years to subsidize the cattle-raising portion of the operations, since the harvest rates are virtually always above sustainable levels. Recently, Faminow [32] has made a more complete analysis of land price trends in Amazonia, and finds that speculative profits cannot explain the attraction of capital to investments in Amazonian ranches. However, a decline in deforestation rate over the 1995–1997 period associated with falling land prices under the Plano Real suggests that speculation had been a significant driver of deforestation.

The decline in deforestation rates from 1987 through 1991 can best be explained by Brazil's deepening economic recession over this period. Ranchers simply lacked money to invest in expanding their clearings as quickly as they had in the past. In addition, the government lacked funds to continue building highways and establishing settlement projects. Probably very little of the decline can be attributed to Brazil's repression of deforestation through inspection from helicopters, confiscating chainsaws and fining landowners caught burning without the required permission from the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). Despite bitter complaints, most people continued to clear anyway. Changes in policies on granting fiscal incentives also do not explain the decline. The decree suspending the granting of new incentives (Decree No. 153) was issued on 25 June 1991—after almost all of the observed decline in deforestation rate had already occurred (see Fig. 2). Even for the last year of the decline (1991), the effect would be minimal, as the aver-

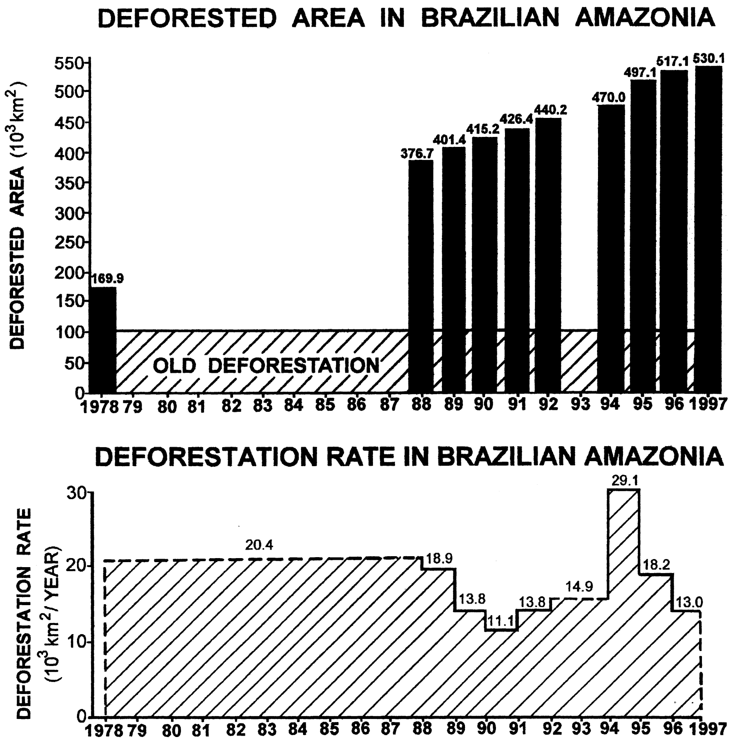

Fig. 2. Rate and extent of deforestation in the Brazilian legal Amazon.

age date for the LANDSAT images for the 1991 data set was August of that year.

The peak in 1995 is probably, in large part, a reflection of economic recovery under the Plano Real, which resulted in larger volumes of money suddenly becoming available for investment, including investment in cattle ranches. The fall in deforestation rates in the years after 1995 is a logical consequence of the Plano Real having sharply cut the rate of inflation. Land values reached a peak in 1995, and subsequently fell by about 50% by the end of 1997 [33]. Falling land values make land speculation unattractive to investors. The association of major swings in deforestation rate with macroeconomic factors such as money availability and inflation rate is one indication that much of the clearing is done by those who invest in medium and large cattle ranches, rather than by small farmers using family labor.

The distribution of 1991 clearing among the region's nine states indicates that most of the clearing took place in states that are dominated by ranchers: the state of Mato Grosso alone accounted for 26% of the 11.1×10^3 km^2 total. Mato Grosso has the highest percentage of its privately held land in ranches of 1000 ha or more: 84% at the time of the last (1985) agricultural census. By contrast, Rondonia—a state that has become notorious for its deforestation by small farmers who arrived on the BR-364 highway that was paved by the World Bank's POLONOROESTE Project in the early 1980 s—accounted for only 10% of the 1991 deforestation total, while Acre had 3%.

The number of properties censused in each size class explained 74% of the variation in deforestation rate per area of private land among the nine Amazonian states in both 1990 and 1991. Multiple regressions indicate that 30% of the clearing in both 1990 and 1991 could be attributed to small farmers (properties < 100 ha in area), and the remaining 70% to either medium or large ranchers [34]. The social cost of substantially reducing deforestation rates would therefore be much less than is implied by frequent pronouncements that blame "poverty" for environmental problems in the region.

Contrary to recent statements by the head of the Brazilian Institute for Environment and Renewable Natural Resources (IBAMA) [35], deforestation data for 1995 and 1996 released by Brazil's National Institute for Space Research (INPE) in January 1988 [36] do not indicate that small farmers are now the primary agents of deforestation. The fact that about half (59% in 1995 and 53% in 1996) of the area of new clearings (as distinct from the area of the properties in which the clearings were located) have areas under 100 ha reinforces the conclusion that most deforestation is being done by ranchers, as no small farmer can clear anywhere near 100 ha in a single year. Only 21% of the area of new clearings in 1995 and 18% in 1996 were under 15 ha. Small farmer families are only capable of clearing about 3 ha $year^{-1}$ with family labor [37], and this is reflected in deforestation behavior in settlement areas [38].

The question of who is to blame for tropical deforestation has profound implications for the priorities of programs intended to reduce forest loss. For example, a "deforestation reduction initiative", later renamed the "alternatives to slash and burn project" aims at achieving these results by promoting agroforestry among small farmers. However, the relationship between the agricultural improvements promoted and reduction of deforestation is undocumented and highly unlikely to be of the level claimed by proponents (5–10 ha saved from the shifting cultivators' axe per ha put under sustainable agriculture) [39]. The prominence of cattle ranchers in Brazil (different from many other parts of the tropics) means that measures aimed at containing deforestation by, for example, promoting agroforestry among small farmers can never achieve this goal, although some of the same tools (such as agroforestry) have important reasons for being supported independent of efforts to combat deforestation [40].

Understanding how deforestation works requires quantitative estimates of effects of the profitability of beef production, roles of land speculation and land prices, incentives, small farmers, land reform, road building, logging, and soybeans. In addition, quantification is needed of economic effects from changes in inflation rate, alternative investments (discount rate), and price and time for transport in different parts of the region.

What is needed are functional (causal) models of deforestation that are disaggregated by socio-economic group and by location within the legal Amazon. Simulations are needed with and without mitigation projects, thereby allowing calculation of the difference between scenarios for the same place. The results can be weighted in accord with timing of emissions and uptakes, as well as monetary flows, to allow fair comparison of options with marked differences in the timing of effects. As is also the case with global circulation models (GCMs) of the atmosphere, policy conclusions must be drawn based on current best estimates despite high levels of uncertainty: postponing actions to counter deforestation (which is also a policy decision) is not likely to be the wisest choice.

Two approaches are frequently mentioned in proposals to use tropical forest maintenance as a carbon offset. One is to set up specific reserves, funding the establishment, demarcation and guarding of these units. Monitoring, in this case, consists of the relatively straightforward process of confirming that the forest stands in question continue to exist. In Amazonia, where large expanses of forest still exist, the reserve approach has the logical weakness of being completely open to "leakage": with the implantation of the project, the people who would have been deforesting in the area established as a reserve will probably clear the same amount of forest somewhere else in the region.

The second approach is through policy changes aimed at reducing the rate of clearing in the Amazon region as a whole (not limited to specific reserves or areas of forest). This second approach has the great advantage of addressing more fundamental aspects of the tropical deforestation problem, but has the disadvantages of not assuring the permanence of forest and of not resulting in a visible product that can be convincingly credited to existence of the project. In order for credit to be assigned to policy change projects, functional models of the deforestation process must be developed that are capable of producing scenarios with and without different policy changes.

6.2. Greenhouse gas emissions from deforestation

Official estimates of Brazilian deforestation rates have been released after long delays, and have often been presented as misleadingly small percentages calculated by the invalid procedure of dividing deforested area by the areas of political units that include substantial portions of savanna, water and other areas not originally forested. On a number of occasions the values released have understated deforestation because of the ways that cloud cover and missing scenes were handled. These problems have been analyzed in detail for estimates of deforestation up to 1988 [41], 1989–1990 [34] and 1991–1994 [2].

Delays in releasing bad news and understatement of the full extent and impact of deforestation form a pattern that has been repeated on too many occasions to be written off as random occurrences. The most recent numbers were released in January 1998 with estimates for 1995 and 1996, and a preliminary value for 1997 [36]. The estimate revealed a tremendous jump in deforestation rate in 1995 to 29.1×10^3 km^2 year^{-1}, almost double the 14.9×10^3 km^2 year^{-1} 1992–1994 rate. The 1996 rate was 18.2×10^3 km^2 year^{-1}, and the preliminary estimate for 1997 was 13.0×10^3 km^2 year^{-1}.

The 1995 and 1996 estimates were ready in November 1997 (and probably substantially earlier in the case of 1995) but were reportedly not released due to orders received by INPE from the office of Brazil's president, in order to spare the president international embarrassment [42]. These estimates were not released until after the December 1997 Kyoto meeting, and also not until after the preliminary estimate had been prepared for 1997 indicating a deforestation rate lower than in the preceding two years (although still very high).

Brazil's official estimates of GHG emissions have produced some extraordinarily low values. On the eve of the 1992 United Nations Conference on Environment and Development

(UNCED), or "ECO-92", in Rio de Janeiro, INPE announced that Brazilian deforestation released only 1.4% of the world's CO_2 emissions [43], a value about three times lower than those derived by this author [44, 45]. Such a low value was obtained by counting only prompt emissions released through the initial burning of the forest, ignoring decomposition and re-burns. Only 39% of the gross release of above-ground carbon, or 27% of the gross release of total carbon (including below-ground biomass and soil carbon) occurs through this pathway for the CO_2 component of net committed emissions [46], updated from [45]).

On the eve of the 1997 conference of the parties to the FCCC, INPE announced that Brazil releases zero net emissions from deforestation [47]. This extraordinary conclusion was apparently reached by ignoring all deforestation emissions other than the initial burn, combined with the belief that the crops planted can somehow absorb this amount of carbon. INPE claimed that "the crops that grow wind up absorbing the carbon that was thrown into the atmosphere by the burning" [47]. Unfortunately, only 7% of the net committed emissions of deforestation are reabsorbed by the replacement landscape [45] (see [48]).

Current estimates of the 1990 emission from deforestation in the Brazilian Legal Amazon are given in Table 1 in terms of net committed emissions and annual balance. "Net committed emissions" refers to the long-term total of emissions and uptakes set in motion by the act of deforestation, and is calculated only for the area cleared in a given year (i.e. the 13.8×10^3 km^2 cleared in 1990). The "annual balance" refers to the emissions and uptakes in a single year (i.e. 1990) over the entire landscape (the 415.2×10^3 km^2 cleared by 1990). Two scenarios are given: "low" and "high" trace gas emissions. These represent a range of emissions factors, or the amount of each gas emitted by different processes such as flaming and smoldering combustion. The range of doubt concerning other important processes, such as forest biomass and deforestation rates at different locations, is not included. The annual balance was higher than the net committed emissions in 1990 because deforestation rates had been higher in the years immediately preceding this year, therefore leaving larger quantities of unburned biomass to produce emissions in the years that followed. The current best estimate for 1990 (Table 1) is 267×10^6 tC of net committed emissions and 353×10^6 tC for the annual balance from deforestation, plus an additional 62×10^6 tC from logging [49] (see [44]). Trace gases are accounted for using the 100-year integration global warming potentials adopted by the second assessment report of the Intergovernmental Panel on Climate Change (IPCC) [18]. Only deforestation (that is, loss of original forest, including both clearing and flooding by hydroelectric dams) is given here, not loss of *cerrado* (the cen-

Table 1
Comparison of methods of calculating the 1990 global warming impact of deforestation in originally forested areas Brazilian Amazonia in millions of tons of CO_2-equivalent carbon

Scenario	Gases included	Net committed emissions (Deforestation only)[a,b]	Annual balance: Deforestation[b] only	Annual balance: Logging	Annual balance: Deforestation[b] + logging
Low trace gas	CO_2 only	254	328	61	389
	CO_2, CH_4, N_2O[c]	267	353	62	415
High trace gas	CO_2 only	254	324	61	385
	CO_2, CH_4, N_2O[c]	278	359	62	422

[a] Infinite time horizon for fluxes from biomass, soil C and replacement vegetation uptake 100-year time horizon for recurrent fluxes (cattle, pasture soil N2O, hydroelectric CH4 and losses of intact forest sources and sinks); 100-year non-coterminous time horizons for impacts; no discounting.[b]For clearing in originally forested areas only (does not include *cerrado* clearing).[c]CO, NO_x and NMHC are also included in the analysis, but the IPCC SAR global warming potentials for these gases are equal to zero

tral Brazilian scrubland that was the original vegetation in about 20% of the legal Amazon). The magnitude of these emissions can be appreciated by comparison with global emissions from automobiles: the world's 400 million automobiles emit 550×10^6 tC annually [50].

That Brazil makes a substantial contribution to global warming will not be deniable after conclusion of the national inventory. The inventory is being compiled by the Ministry of Science and Technology following the standardized methodology developed by the IPCC. This methodology requires inclusion of inherited emissions (in practice represented by committed emission—i.e. assuming a constant rate of deforestation). Defining away emissions from unburned biomass (approximately two-thirds of the total from deforestation) will no longer be possible.

Most important is understanding that the fact that Amazonian deforestation makes a substantial contribution to global warming represents an opportunity for Brazil to gain financial benefits and to gain assistance in achieving the goal of reducing deforestation, which has been announced as an objective of the government on numerous occasions for reasons completely independent of global warming concerns.

6.3. Programs to slow deforestation

Current efforts to contain deforestation include the pilot program to conserve the Brazilian rainforest (PPG-7), financed by the G-7 countries and administered by the World Bank. Components already being implemented as of 1998 include the "PD/A" demonstration projects (small projects carried out by non-governmental organizations), extractive reserves, indigenous lands, and support for scientific research centers and directed research projects. Projects expected to begin soon include natural resources policy (i.e. zoning), natural resources management (mainly forestry), varzea (floodplain) management, parks and reserves, fire and deforestation control (i.e. detection of deforestation and burning), and monitoring and analysis of pilot program activities in order to learn policy lessons. Activities for which proposals are under preparation (for integration into the PD/A component) include recuperation of degraded lands, environmental education and indigenous and private sector demonstration projects.

In addition to the pilot program, the Brazilian government has a number of other programs aimed at controlling deforestation. These can be seen on the website of the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA): http://www.ibama.gov.br

The most basic problem in controlling deforestation is that much of what needs to be done is outside the purview of agencies such as IBAMA that are responsible for dealing with environmental problems. Authority to change tax laws, resettlement policies, and road-building priorities, for example, rest with other parts of the government. Steps needed to reduce deforestation include: applying heavy taxes to take any profit out of land speculation, changing land titling procedures to cease recognizing deforestation for cattle pasture as an "improvement" (benfeitoria), removing remaining subsidies, reinforcing procedures for environmental impact reports (RIMAs), carrying out agrarian reform both in Amazonia and in the source areas of migrants, and offering alternative employment both in rural and in urban areas [51].

Although small farmers account for only 30% of the deforestation activity, the intensity of deforestation within the area they occupy is greater than for the medium and large ranchers that hold 89% of the legal Amazon's private land. Deforestation intensity, or the impact per km^2 of private land, declines with increasing property size. This means that deforestation would increase if forest areas now held by large ranches were redistributed into small holdings. This indicates the importance of using already cleared areas for agrarian reform, rather than following the politically easier path of distributing areas still in forest. Large as the area already cleared is, it has limits that fall far short of the potential demand for land to be settled. Indeed, even the legal Amazon as a whole falls short of this demand [52]. Recognizing the existence of carrying capacity limits, and then maintaining population levels within these, is fundamental to any long-term plan for sustainable use of Amazonia [53, 54].

7. Role of the private sector

Creation of opportunities for workable private–public partnerships is to be the task of a special sector that is currently in the process of being created within the Secretariat of the legal Amazon in the Ministry of the Environment, Water Resources and the Legal Amazon (MMA) (see: http://www.sca.mma.gov.br). Non-governmental actors also serve as intermediaries in matching interested private sector parties with environmentally beneficial investment opportunities (for example, the Brazilian Foundation for Sustainable Development [FBDS], located in Rio de Janeiro).

Private investors will want assurance that the rules of the game have been settled before investing in carbon offsets in the forest sector. Much remains to be decided; many items related to these options will undoubtedly be open for discussion in Buenos Aires at the November 1998 conference of the parties to the FCCC.

The nature of the global warming response options that are most attractive in Brazil makes special institutional arrangements necessary. While plantations can be executed as small free-standing projects, efforts to reduce deforestation require coordinated efforts that are beyond the capacities of any single investor. These include substantial investment in research before any "real" carbon benefits can be claimed. They also involve significant risk of failure, although the much higher potential carbon benefits from these efforts make deforestation reduction the top priority.

Thought must therefore be given to assigning risk, and to viable remedies in the case of non-compliance with implementation agreements in this sector. The logical instrument would appear to be reimbursement of the companies or governments for the money invested in response options that do not result in the promised carbon benefits. However, such a mechanism substantially complicates approval of the projects by the Brazilian government, as demonstrated by the history of the PPG-7 pilot program. If Brazilian government guarantees of reimbursement are required (as Germany demanded initially for the PD/A projects), then funds are no longer considered a "gift", and therefore have to be included in the national budget and passed through the National Congress (implying a lead time of over one year, plus substantial risk of being reduced and/or delayed).

Monitoring and verification of results is especially important in the case of deforestation reduction activities. The need for independence of the monitoring body cannot be overemphasized (see [2]). Much needs to be monitored in addition to carbon stocks and flows, including government policies related to deforestation, and environmental and social (including human rights) problems in areas where project or program activities take place.

8. Conclusions

Deforestation avoidance has the largest potential for combating global warming in the Brazilian forest sector. Efforts aimed at policy changes have the greatest potential effect in this area, but much depends on how carbon benefits are counted. While much remains to be done to make deforestation reduction into a global warming response option that can demonstrate "real" carbon benefits as expected by the clean development mechanism, it is imperative that the needed efforts be made to develop this option.

Silvicultural plantations, while much closer to offering eligible projects for investment, have inherently lower potential. In the case of plantations, the principal barriers are social rather than technical. Mechanisms are needed to ensure that unacceptable social impacts do not result from plantation expansion programs, particularly in the case of plantations for charcoal production (which have the greatest potential carbon benefits among plantation options).

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Appendix A

"Available" fossil fuel C stocks were calculated by Bolin and coworkers [55, p. 33], based on Perry and Landsberg [56]. Stocks in the biosphere total approximately 2190×10^9 tC, of which 610×10^9 tC is live vegetation and 1580×10^9 tC is detritus and soils (Schimel and coworkers [57, p. 77]). Much of the soils portion of this is not "at risk" of release: only 18.3×10^9 tC would be released from the top meter of soil if all tropical forests were converted to other land uses. The tropical forest portion of the global carbon stocks is estimated at 198.5×10^9 tC, which, together with the 18.3×10^9 tC of "at risk" soil carbon, less 17.4×10^9 tC in the landscape that would replace tropical forests, would bring the total to 216.8×10^9 tC.

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